

**WHAT IS CLAIMED IS:**

1. A method for increasing the capability of a network topology model having a plurality of nodes connected by existing links to maintain service continuity in the presence of faults, said method comprising:
  - (a) adding new links to the network topology model to protect against single node failures; and
  - (b) adjusting link weights for the network topology model to reduce at least one of a cost of network operation, and an imbalance in link utilizations.
2. A method for increasing the capability of a network topology model as defined in Claim 1, wherein said adjusting link weights in step (b) is performed to reduce said imbalance in link utilizations without deteriorating said cost of network operation.
3. A method for increasing the capability of a network topology model as defined in Claim 1, wherein said adjusting link weights in step (b) is performed to reduce said cost of network operation without increasing said imbalance in link utilizations.
4. A method for increasing the capability of a network topology model as defined in Claim 1, wherein said adjusting link weights in step (b) is performed to reduce said cost of network operation without increasing said imbalance in link utilizations while keeping the utilization for each link below a specific threshold.
5. A method for increasing the capability of a network topology model as defined in Claim 1, further comprising the step of:
  - (c) adding links to the network topology model to reduce the cost of network operation.
6. A method for increasing the capability of a network topology model as defined in Claim 1, wherein step (a) comprises the sub-steps of:
  - (a) failing one of the plurality of nodes in the network topology;
  - (b) calculating a first number of disconnected node pairs;

- (c) selecting a pair of nodes which are neighbors to the failed node;
- (d) adding a new link between the pair of nodes;
- (e) calculating a second number of disconnected node pairs;
- (f) retaining the new link and setting the first number equal to the second number when the second number is less than the first number;
- (g) repeating steps (c) through (f) for randomly selected combination of pair of nodes until the first number equals zero;
- (h) repeating steps (a) through (g) for each of the plurality of nodes in the network topology as modified by the addition of the retained links;
- (i) removing one of the plurality of retained links in the modified network topology;
- (j) restoring the removed link when the removal causes any node pair to become disconnected for any single node failure; and
- (k) repeating steps (i) through (k) for each of the plurality of retained new links in the modified network topology.

7. A method for increasing the capability of a network topology model as defined in Claim 1, wherein said adjusting link weights for the network topology model to reduce the cost of network operation in step (b) comprises the sub-steps of:

- (a) unmarking each link in the network topology;
- (b) calculating a network cost for operating the current network topology based upon a link cost associated with each link;
- (c) incrementing the weight of the unmarked link in the current network topology having the maximum link cost to modify the network topology;
- (d) calculating a network cost for operating the modified network topology;
- (e) restoring the weight and marking the link having the maximum link cost when the network cost for operating the modified network topology is greater than or equal to the network cost for operating the current network topology; and
- (f) repeating steps (b) through (e) until each of the links in the network topology is marked.

8. A method for increasing the capability of a network topology model as defined in Claim 7, wherein:

said sub-step (b) in step (b) further comprises determining survivability characteristics of the current network topology;

said sub-step (d) in step (b) further comprises determining the survivability characteristics of the modified network topology; and

said sub-step (g) in step (b) for restoring the weight and marking the link having the maximum link cost is performed when at least one of:

the survivability characteristics of the modified network has deteriorated in comparison to the survivability characteristics of the current network topology; and

the network cost for operating the modified network topology is greater than or equal to the network cost for operating the current network topology.

9. A method for increasing the capability of a network topology model as defined in Claim 5, wherein step (c) comprises the sub-steps of:

(a) selecting a maximum number of potential links to be added to the network topology;

(b) selecting a maximum number of new links to be added to the network topology;

(c) finding a potential link that when added to the current network topology will result in a maximum reduction in the cost of network operation;

(d) adding the potential link to the current network topology;

(e) repeating steps (c) and (d) until the maximum number of potential links have been added to the current network topology;

(f) finding the potential link that when removed from the current network topology will result in the lowest cost of network operation;

(g) removing the potential link from the current network topology;

(h) repeating steps (f) and (g) until the maximum number of potential links is reduced to the maximum number of new links to be added to the network topology.

10. A method for increasing the capability of a network topology model as defined in Claim 1, wherein said adjusting link weights for the network topology

model to reduce the imbalance in link utilizations in step (b) comprises the sub-steps of:

- (a) unmarking all of the links in the network topology;
- (b) calculating a standard deviation of link utilization for the current network topology;
- (c) incrementing the weight of the unmarked link in the current network topology having the maximum utilization to modify the network topology;
- (d) calculating a standard deviation of link utilization for the modified network topology;
- (e) restoring the weight and marking the link having the maximum utilization when the standard deviation of link utilization for the current topology is less than the standard deviation of link utilization for the modified topology; and
- (f) repeating steps (b) through (e) until each of the links in the network topology is marked.

11. A method for increasing the capability of a network topology model as defined in Claim 10, wherein:

said sub-step (b) in step (b) further comprises determining survivability characteristics of the current network topology;

said sub-step (d) in step (b) further comprises determining the survivability characteristics of the modified network topology; and

said sub-step (g) in step (b) for restoring the weight and marking the link having the maximum link cost is performed when at least one of:

the survivability characteristics of the modified network has deteriorated in comparison to the survivability characteristics of the current network topology; and

the standard deviation of link utilization for the current topology is less than the standard deviation of link utilization for the modified topology.

12. A method for increasing the capability of a network topology model as defined in Claim 2, wherein step (b) comprises the sub-steps of:

- (a) calculating a network cost for operating the current network topology based upon a link cost associated with each link;

- (b) unmarking all of the links in the network topology;
- (c) calculating a standard deviation of link utilization for the current topology;
- (d) incrementing the weight of the unmarked link in the current network topology having the maximum utilization to modify the network topology;
- (e) calculating a network cost for operating the modified network topology;
- (f) calculating a standard deviation of link utilization for the modified network topology;
- (g) restoring the weight and marking the link having the maximum link cost when at least one of:
  - the network cost for operating the modified network topology is greater than or equal to the network cost for operating the current network topology; and
  - the standard deviation of link utilization for the current topology is less than the standard deviation of link utilization for the modified topology; and
- (h) repeating steps (d) through (g) until each of the links in the network topology is marked.

13. A method for increasing the capability of a network topology model as defined in Claim 12, wherein:

- said sub-step (c) in step (b) further comprises determining survivability characteristics of the current network topology;
- said sub-step (e) in step (b) further comprises determining the survivability characteristics of the modified network topology; and
- said sub-step (g) in step (b) for restoring the weight and marking the link having the maximum link cost is performed when at least one of:
  - the survivability characteristics of the modified network has deteriorated in comparison to the survivability characteristics of the current network topology;
  - the network cost for operating the modified network topology is greater than or equal to the network cost for operating the current network topology; and
  - the standard deviation of link utilization for the current topology is less than the standard deviation of link utilization for the modified topology.

14. A method for increasing the capability of a network topology model as defined in Claim 3, wherein step (b) comprises the sub-steps of:

- (a) calculating a standard deviation of link utilization for the current network topology;
- (b) unmarking all of the links in the network topology;
- (c) calculating a network cost for operating the current network topology based upon a link cost associated with each link;
- (d) incrementing the weight of the unmarked link in the current network topology having the maximum cost to modify the network topology;
- (e) calculating a network cost for operating the modified network topology;
- (f) calculating a standard deviation of link utilization for the modified network topology;
- (g) restoring the weight and marking the link having the maximum link cost when at least one of:
  - the network cost for operating the modified network topology is greater than or equal to the network cost for operating the current network topology; and
  - the standard deviation of link utilization for the current network topology is less than the standard deviation of link utilization for the modified network topology;
- (h) repeating steps (c) through (g) until each of the links in the network topology is marked.

15. A method for increasing the capability of a network topology model as defined in Claim 14, wherein:

- said sub-step (c) in step (b) further comprises determining survivability characteristics of the current network topology;
- said sub-step (e) in step (b) further comprises determining the survivability characteristics of the modified network topology; and
- said sub-step (g) in step (b) for restoring the weight and marking the link having the maximum link cost is performed when at least one of:

the survivability characteristics of the modified network has deteriorated in comparison to the survivability characteristics of the current network topology;

the network cost for operating the modified network topology is greater than or equal to the network cost for operating the current network topology; and

the standard deviation of link utilization for the current network topology is less than the standard deviation of link utilization for the modified network topology.

16. A method of adjusting link weights as defined in Claim 14, further comprising the sub-step of:

(i) increasing the link capacity such that the link utilization is no longer higher than a specified threshold.

17. A method for adding new links to a network topology model having a plurality of nodes connected by existing links to achieve protection against single node failures for Open Shortest Path First (OSPF) and Multiprotocol Label Switching (MPLS) based local recovery, said method comprising the steps of:

(a) failing one of the plurality of nodes in the network topology;

(b) calculating a first number of disconnected node pairs;

(c) selecting a pair of nodes which are neighbors to the failed node;

(d) adding a new link between the pair of nodes;

(e) calculating a second number of disconnected node pairs;

(f) retaining the new link and setting the first number equal to the second

number when the second number is less than the first number;

(g) repeating steps (c) through (f) for randomly selected combination of pair of nodes until the first number equals zero;

(h) repeating steps (a) through (g) for each of the plurality of nodes in the network topology as modified by the addition of the retained links;

(i) removing one of the plurality of retained links in the modified network topology;

(j) restoring the removed link when the removal causes any node pair to become disconnected for any single node failure; and

(k) repeating steps (i) through (k) for each of the plurality of retained new links in the modified network topology.

18. A method for adjusting link weights for a network topology model having a plurality of nodes connected by links to reduce the cost of network operation, said method comprising the steps of:

- (a) unmarking each link in the network topology;
- (b) calculating a network cost for operating the current network topology based upon a link cost associated with each link;
- (c) incrementing the weight of the unmarked link in the current network topology having the maximum link cost to modify the network topology;
- (d) calculating a network cost for operating the modified network topology;
- (e) restoring the weight and marking the link having the maximum link cost when the network cost for operating the modified network topology is greater than or equal to the network cost for operating the current network topology; and
- (f) repeating steps (b) through (e) until each of the links in the network topology is marked.

19. A method for increasing the capability of a network topology model as defined in Claim 18, wherein:

said sub-step (b) in step (b) further comprises determining survivability characteristics of the current network topology;

said sub-step (d) in step (b) further comprises determining the survivability characteristics of the modified network topology; and

said sub-step (g) in step (b) for restoring the weight and marking the link having the maximum link cost is performed when at least one of:

the survivability characteristics of the modified network has deteriorated in comparison to the survivability characteristics of the current network topology; and

the network cost for operating the modified network topology is greater than or equal to the network cost for operating the current network topology.



20. A method for adding links to a network topology model having a plurality of nodes connected by existing links to reduce the cost of network operation, said method comprising the steps of:

- (a) selecting a maximum number of potential links to be added to the network topology;
- (b) selecting a maximum number of new links to be added to the network topology;
- (c) finding a potential link that when added to the current network topology will result in a maximum reduction in the cost of network operation;
- (d) adding the potential link to the current network topology;
- (e) repeating steps (c) and (d) until the maximum number of potential links have been added to the current network topology;
- (f) finding the potential link that when removed from the current network topology will result in the lowest cost of network operation;
- (g) removing the potential link from the current network topology;
- (h) repeating steps (f) and (g) until the maximum number of potential links is reduced to the maximum number of new links to be added to the network topology.

21. A method of adjusting link weights in a network topology model having a plurality of nodes connected by links to reduce an imbalance in link utilizations, said method comprising the steps of:

- (a) unmarking all of the links in the network topology;
- (b) calculating a standard deviation of link utilization for the current network topology;
- (c) incrementing the weight of the unmarked link in the current network topology having the maximum utilization to modify the network topology;
- (d) calculating a standard deviation of link utilization for the modified network topology;
- (e) restoring the weight and marking the link having the maximum utilization when the standard deviation of link utilization for the current topology is less than the standard deviation of link utilization for the modified topology; and

(f) repeating steps (b) through (e) until each of the links in the network topology is marked.

22. A method for increasing the capability of a network topology model as defined in Claim 21, wherein:

said sub-step (b) in step (b) further comprises determining survivability characteristics of the current network topology;

said sub-step (d) in step (b) further comprises determining the survivability characteristics of the modified network topology; and

said sub-step (g) in step (b) for restoring the weight and marking the link having the maximum link cost is performed when at least one of:

the survivability characteristics of the modified network has deteriorated in comparison to the survivability characteristics of the current network topology; and

the standard deviation of link utilization for the current topology is less than the standard deviation of link utilization for the modified topology.

23. A method of adjusting link weights in a network topology model having a plurality of nodes connected by links to reduce an imbalance in link utilizations without deteriorating the cost of network operation, said method comprising the steps of:

(a) calculating a network cost for operating the current network topology based upon a link cost associated with each link;

(b) unmarking all of the links in the network topology;

(c) calculating a standard deviation of link utilization for the current topology;

(d) incrementing the weight of the unmarked link in the current network topology having the maximum utilization to modify the network topology;

(e) calculating a network cost for operating the modified network topology;

(f) calculating a standard deviation of link utilization for the modified network topology;

(g) restoring the weight and marking the link having the maximum link cost when at least one of:

the network cost for operating the modified network topology is greater than or equal to the network cost for operating the current network topology; and

the standard deviation of link utilization for the current topology is less than the standard deviation of link utilization for the modified topology; and

(h) repeating steps (d) through (g) until each of the links in the network topology is marked.

24. A method for increasing the capability of a network topology model as defined in Claim 23, wherein:

said sub-step (c) in step (b) further comprises determining survivability characteristics of the current network topology;

said sub-step (e) in step (b) further comprises determining the survivability characteristics of the modified network topology; and

said sub-step (g) in step (b) for restoring the weight and marking the link having the maximum link cost is performed when at least one of:

the survivability characteristics of the modified network has deteriorated in comparison to the survivability characteristics of the current network topology;

the network cost for operating the modified network topology is greater than or equal to the network cost for operating the current network topology; and

the standard deviation of link utilization for the current topology is less than the standard deviation of link utilization for the modified topology.

25. A method of adjusting link weights in a network topology model having a plurality of nodes connected by links to reduce the cost of network operation without increasing an imbalance in link utilizations, said method comprising the steps of:

(a) calculating a standard deviation of link utilization for the current network topology;

(b) unmarking all of the links in the network topology;

(c) calculating a network cost for operating the current network topology based upon a link cost associated with each link;

(d) incrementing the weight of the unmarked link in the current network topology having the maximum cost to modify the network topology;

(e) calculating a network cost for operating the modified network topology;

(f) calculating a standard deviation of link utilization for the modified network topology;

(g) restoring the weight and marking the link having the maximum link cost when at least one of:

the network cost for operating the modified network topology is greater than or equal to the network cost for operating the current network topology; and

the standard deviation of link utilization for the current network topology is less than the standard deviation of link utilization for the modified network topology; and

(h) repeating steps (c) through (g) until each of the links in the network topology is marked.

26. A method for increasing the capability of a network topology model as defined in Claim 25, wherein:

said sub-step (c) in step (b) further comprises determining survivability characteristics of the current network topology;

said sub-step (e) in step (b) further comprises determining the survivability characteristics of the modified network topology; and

said sub-step (g) in step (b) for restoring the weight and marking the link having the maximum link cost is performed when at least one of:

the survivability characteristics of the modified network has deteriorated in comparison to the survivability characteristics of the current network topology;

the network cost for operating the modified network topology is greater than or equal to the network cost for operating the current network topology; and

the standard deviation of link utilization for the current network topology is less than the standard deviation of link utilization for the modified network topology.

27. A method of adjusting link weights as defined in Claim 25, further comprising the step of:

(i) increasing the link capacity such that the link utilization is no longer higher than a specified threshold.

28. An article of manufacture for increasing the capability of a network topology model having a plurality of nodes connected by existing links to maintain service continuity in the presence of faults, said article comprising:

a machine readable medium containing one or more programs which when executed implement the steps of:

(a) adding new links to the network topology model to protect against single node failures; and

(b) adjusting link weights for the network topology model to reduce at least one of a cost of network operation, and an imbalance in link utilizations.

29. An article of manufacture as defined in Claim 28, wherein said machine readable medium is configured to reduce said imbalance in link utilizations without deteriorating said cost of network operation.

30. An article of manufacture as defined in Claim 28, wherein said machine readable medium is configured to reduce said cost of network operation without increasing said imbalance in link utilizations.

31. An article of manufacture as defined in Claim 28, wherein said machine readable medium is configured to reduce said cost of network operation without increasing said imbalance in link utilizations while keeping the utilization for each link below a specific threshold.

32. An article of manufacture as defined in Claim 28, wherein said machine readable medium is configured to perform the additional step of:

(c) adding links to the network topology model to reduce the cost of network operation.

33. An apparatus for increasing the capability of a network topology model having a plurality of nodes connected by existing links to maintain service continuity in the presence of faults, said apparatus comprising:

a network topology analyzing unit configured to:

(a) add new links to the network topology model to protect against single node failures; and

(b) adjust link weights for the network topology model to reduce at least one of a cost of network operation, and an imbalance in link utilizations.